Optical spectroscopy of the heaviest elements

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The investigation of atomic, chemical and nuclear properties of heavy elements with charge numbers of Z > 100 is a real challenge. Heavy elements are produced in nuclear fusion reactions with rates of sometimes only a few atoms per week [1]. Their life-times are short, occasionally only in the order of milliseconds. At present, the most advanced method for the investigation of the properties of heavy elements is chemistry on single atoms in aqueous solutions [2] and in the gas phase [3]. This technique has already yielded detailed chemical information up to Z=108 [4]. Such experiments aid in the investigation of relativistic effects. For the heaviest elements these may result in alterations from expectations within a period of homologue elements. Relativistic effects, roughly speaking, originate from a shrinkage of the wave functions of inner shell electrons which, in turn, influence the binding energy of the valence electrons and thus the chemical properties. In the actinide region these are the 5f-, 6d-, 7p- and 7s- orbitals. Therefore, a more direct approach to investigate relativistic effects may be to study first ionization potentials (IP) or, even better, the atomic level schemes, both experimentally and by relativistic ab-initio multiconfiguration Dirac-Fock (MCDF) calculations or other methods [5-7]. However, any atomic spectroscopy, even with the most sensitive laser methods, is hampered by the fact that a broad band search for levels is limited due to the small number of atoms available for the studies. To obtain reliable information under these circumstances, it is necessary to incorporate theoretical level predictions in performing the experiments.

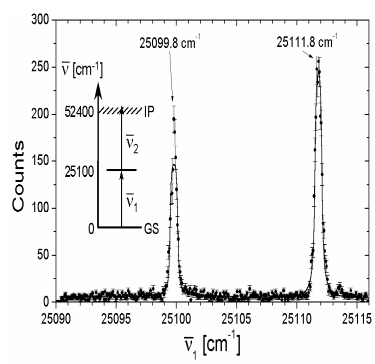

Figure 1. Observed levels in Fermium. The full line shows the best fit of a power broadened line profile to the data.

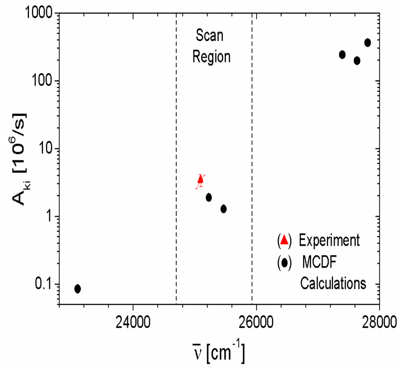

Figure 2. Partial transition rates to the $5f^{12}\,7s^2\ {}^3H^e_6$ ground state as function of the level energie $\bar{\upsilon}$.

In this contribution we report our successful search for predicted atomic levels for elemental fermium for which experimental information was not available previously. The experiments [8] were performed with only a sample of 2.7×10^{10} atoms of the isotope ^{255}Fm which was bred in the high flux isotope reactor at ORNL, USA. The atoms with a half-life of 20.1 h were evaporated at a temperature of about 1,000 °C from a filament and stored in the argon buffer gas of an optical cell [9]. Atomic levels were sought by the method of resonance ionization spectroscopy using an excimer-dye-laser combination. Two atomic levels were found at wave numbers (25,099.8 ± 0.2) cm^{-1} and (25,111.8 ± 0.2) cm^{-1}, see Fig. 1. Partial transition rates to the $5f^{12}\ 7s^2\ {}^3H^e_6$ ground state have been determined from their saturation characteristics. By comparison of the absolute level energies, as well as the partial transition rates with Multiconfiguration-Dirac-Fock (MCDF) calculations, term assignments of the observed levels are proposed. The calculations suggest that the leading orders of these levels could be the $5f^{12}\ 7s7p\ {}^5I^o_6$ and $5f^{12}\ 7s7p\ {}^5G^o_5$ term.

In a follow up experiment the three optical transitions around 27,500 cm^{-1} with large Einstein-coefficients of about $3{\cdot}10^8$/s were sought for. Five additional lines were found in the wave number region of 27,100 to 28,400 cm^{-1}, see Fig. 3. A possible term assignment will be discussed.

Due to the small samples which were available, the ionization potential of fermium could not be determined, so far. However, an upper limit of 52,140 cm^{-1} was deduced from the experiment. This is in agreement with extrapolations of spectral properties, which yield IP=52,400(600) [10] and MCDF calculations which yield IP=50,800(2400) cm^{-1} [11].

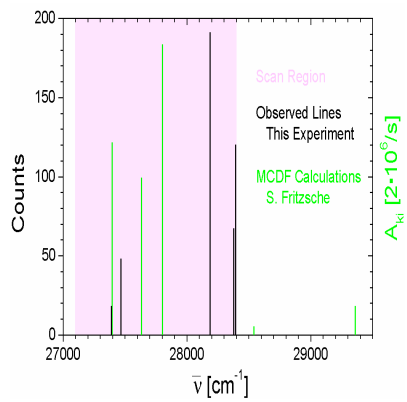

Figure 3. Wavenumber scan from 27,100 cm^{-1} to 28,4000 cm^{-1} and MCDF calculations.

References

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